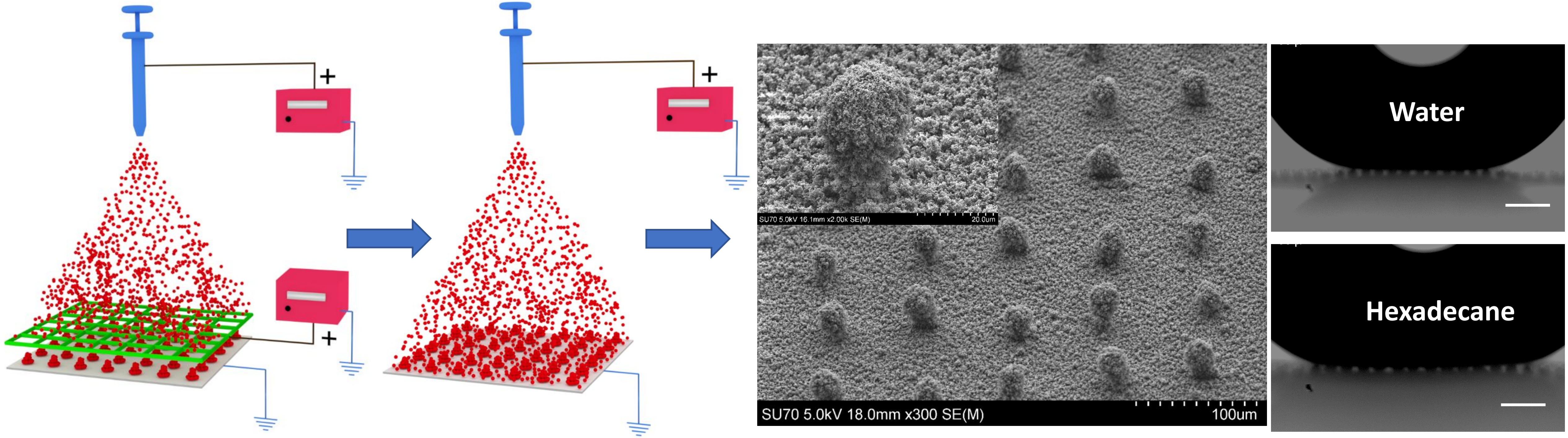
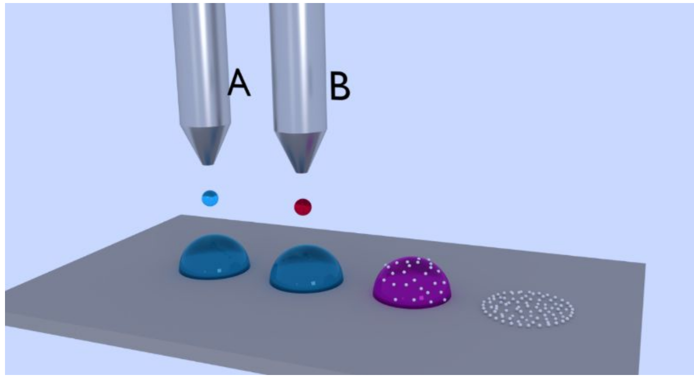
Research Thrust 2:
Particle/fiber-enabled Technology

This thrust works on the research and development of the technologies enabled by particles and/or fibers. The major research areas include (but not limited to) additive manufacturing, surface coating/treatment, and catalytic processes. Through experimental and modeling studies, the particle/fiber-enabled technology can be optimized to meet current and future requirements in various applications. This thrust also explores innovative technologies to open up future applications.

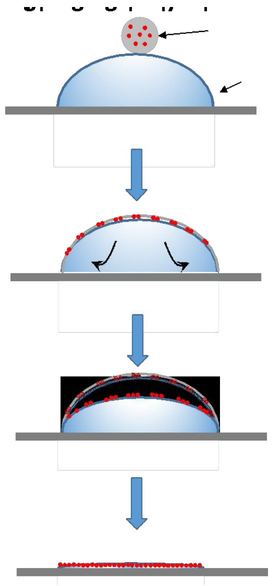


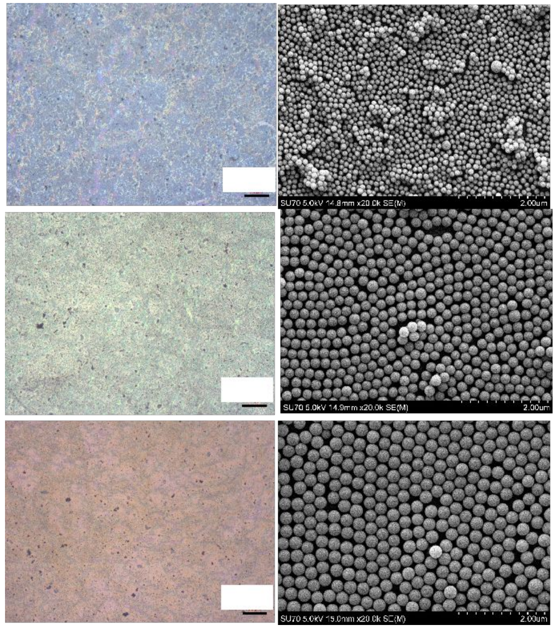
Surfaces patterned with multiscale roughness were obtained by focusing the electrosprayed deposition through a mesh mask, followed by overlaying a random hierarchical roughness of electrosprayed nanoparticles. All the textured surfaces were treated with a low surface energy fluoropolymer to render superhydrophobicity and superoleophobicity.

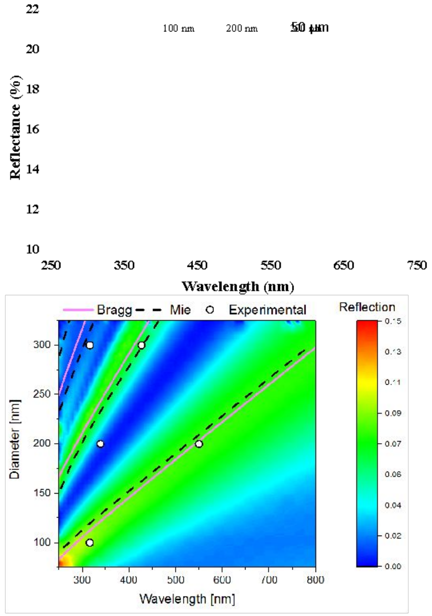
Al-Milaji, K.N., **Zhao, H.***, Fabrication of Superoleophobic Surfaces by Mask-assisted Electrospray, *Applied Surface Science*, 2017, 396, 955–964



Interfacial self-assembly

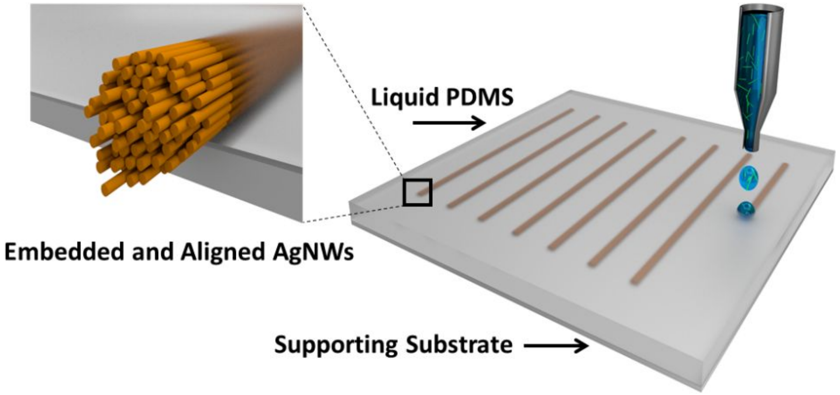


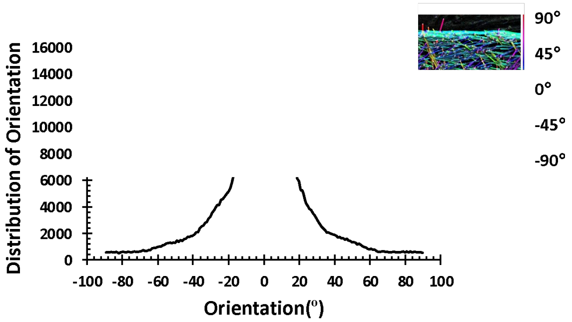


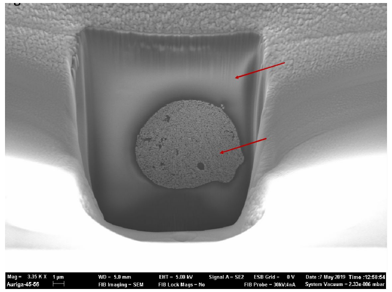


Self-assembly of colloidal particles in a dual-droplet inkjet printing configuration is demonstrated to produce a nearly monolayer closely packed deposition of colloidal particles that exhibits structural color. By controlling the ink surface tensions and jetting parameters, the wetting droplets (the second droplet) containing colloidal nanoparticles quickly spread over the supporting droplets (the first droplet) upon impact. The well-ordered deposition is achieved by tuning the solvent composition of the wetting droplets and functionalization of the nanoparticles to facilitate network formation at the air–droplet interface.

Al-Milaji, K.N., Secondo, R.R., Ng, T.N., Kinsey, N., **Zhao, H.***, Interfacial Self-Assembly of Colloidal Nanoparticles in Dual-Droplet Inkjet Printing, *Advanced Materials Interfaces*, 2018, 5, 1701561

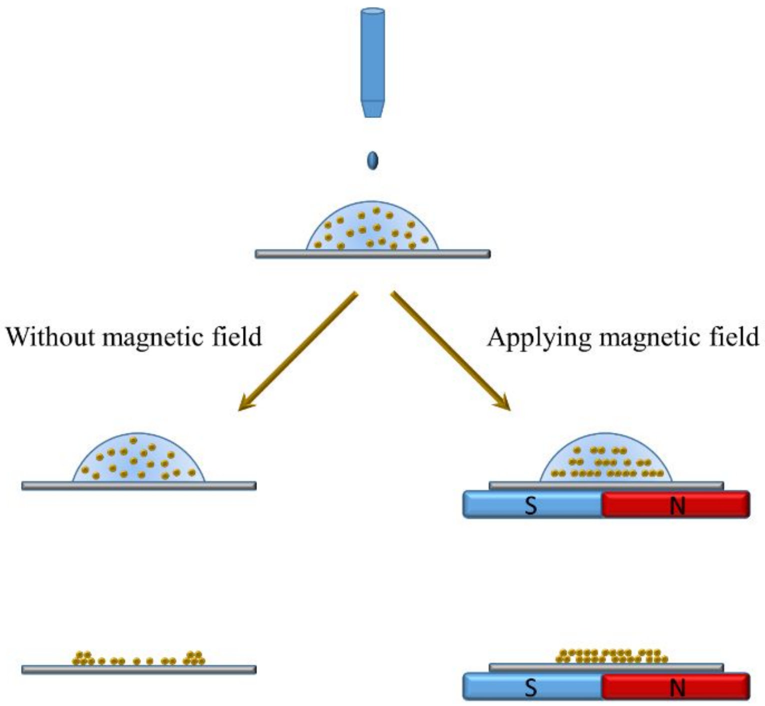


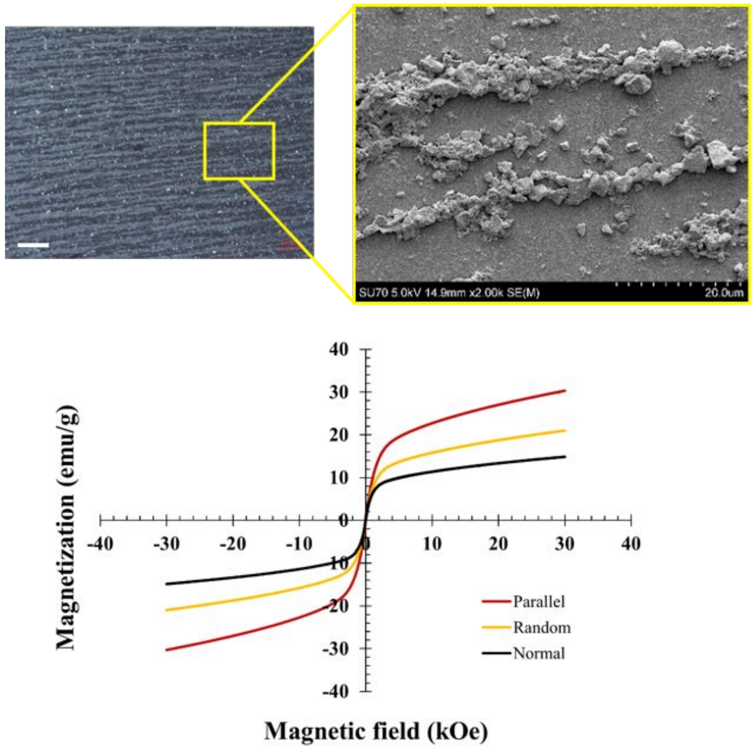




Stretchable conductors composed of embedded silver nanowires have been fabricated in a single step, where silver nanowires are directly printed into an uncured liquid elastomer layer to form the aligned and embedded conductive lines.

Al-Milaji, K.N., Huang, Q., Li, Z., Ng, T.N., **Zhao, H.***, Direct Embedment and Alignment of Silver Nanowires by Inkjet Printing for Stretchable Conductors, *ACS Applied Electronic Materials*, 2020, 2, 3289-3298



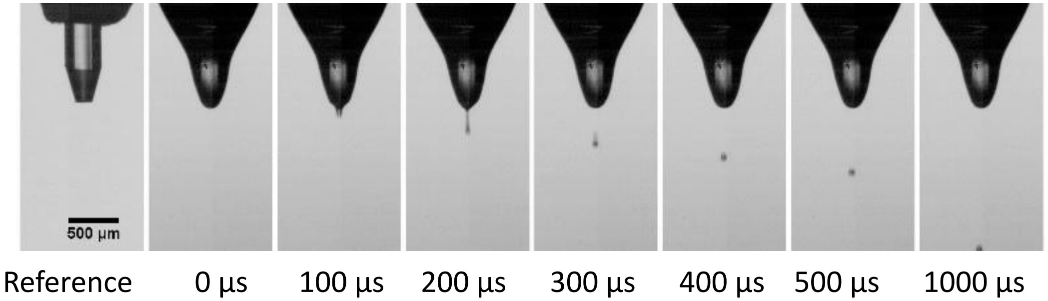


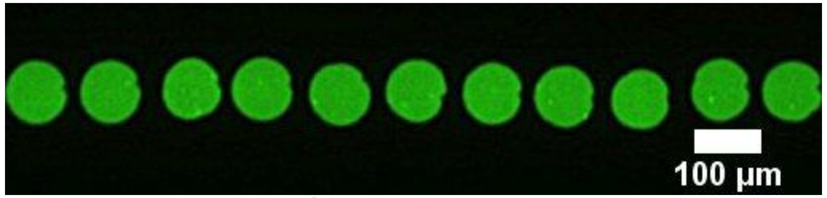
This study examines the effect of externally applied magnetic field on particle deposition patterns. The magnetic field not only suppresses the coffee-ring effect, but also align the magnetic particles and render the anisotropic magnetic properties.

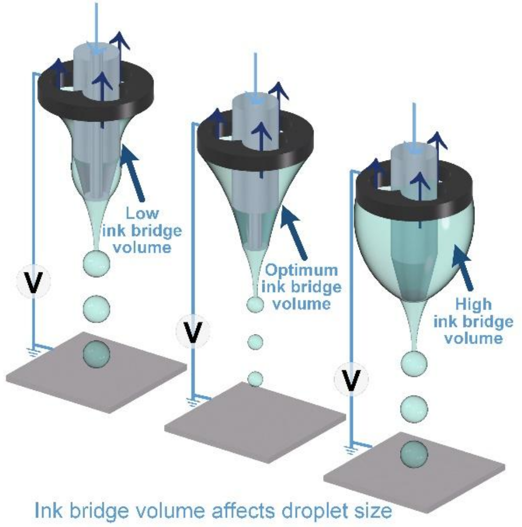
Al-Milaji, K.N., Hadimani, R.L., Gupta, S., Pecharsky, V.K., **Zhao, H.***, Inkjet Printing of Magnetic Particles Toward Anisotropic Magnetic Properties, *Scientific Reports*, 2019, 9, 16261.

A coaxial nozzle, consisting of two coaxially aligned capillaries to minimize the nozzle clogging by enabling continuous ink circulation has been demonstrated for electrohydrodynamic (EHD) printing.

The ink bridge volume affects the volume and shape of the jetting meniscus, which is directly correlated to the printed dot size. A closed-loop feedback control was developed to automatically regulate the volume of the ink bridge during the printing.

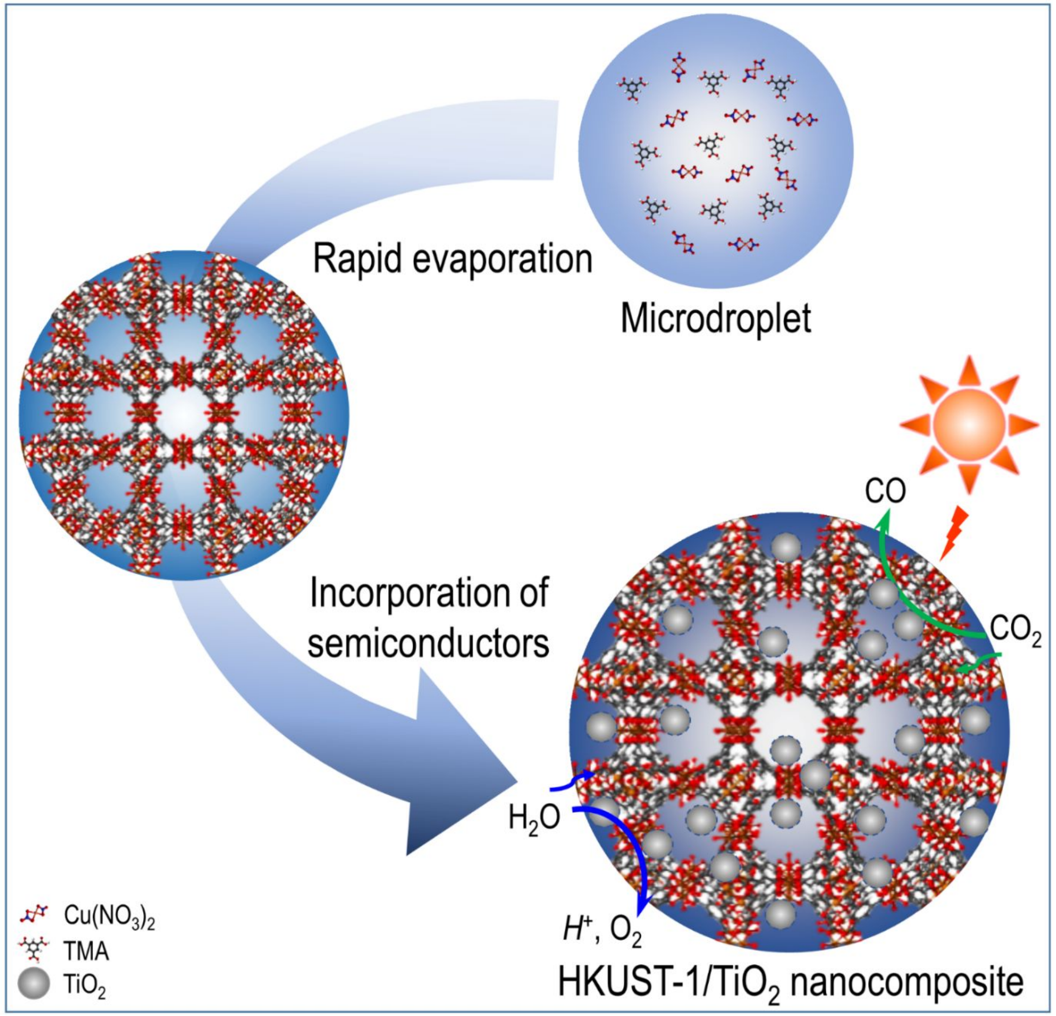






Li, Z., Al-Milaji, K.N., **Zhao, H.***, Chen, D.R.*, Ink Bridge Control in the Electrohydrodynamic Printing with a Coaxial Nozzle, *Journal of Manufacturing Processes*, 2020, 60, 418-425

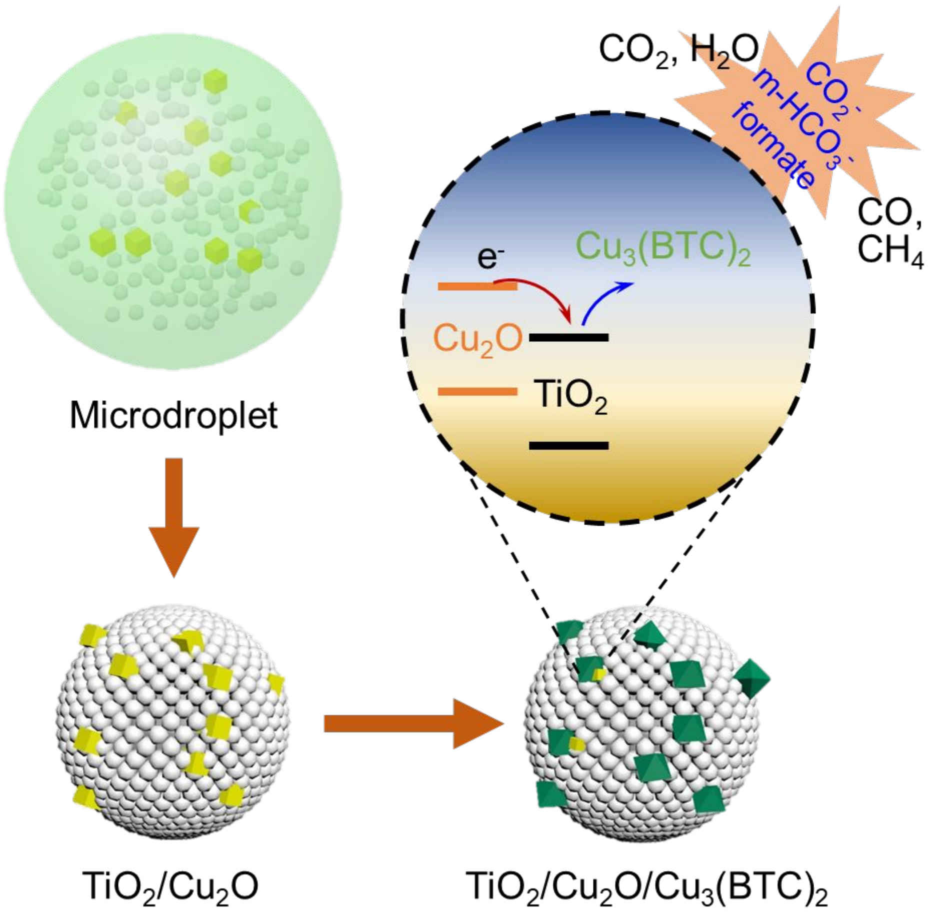
Example 1_ MOFs-based catalyst particle design

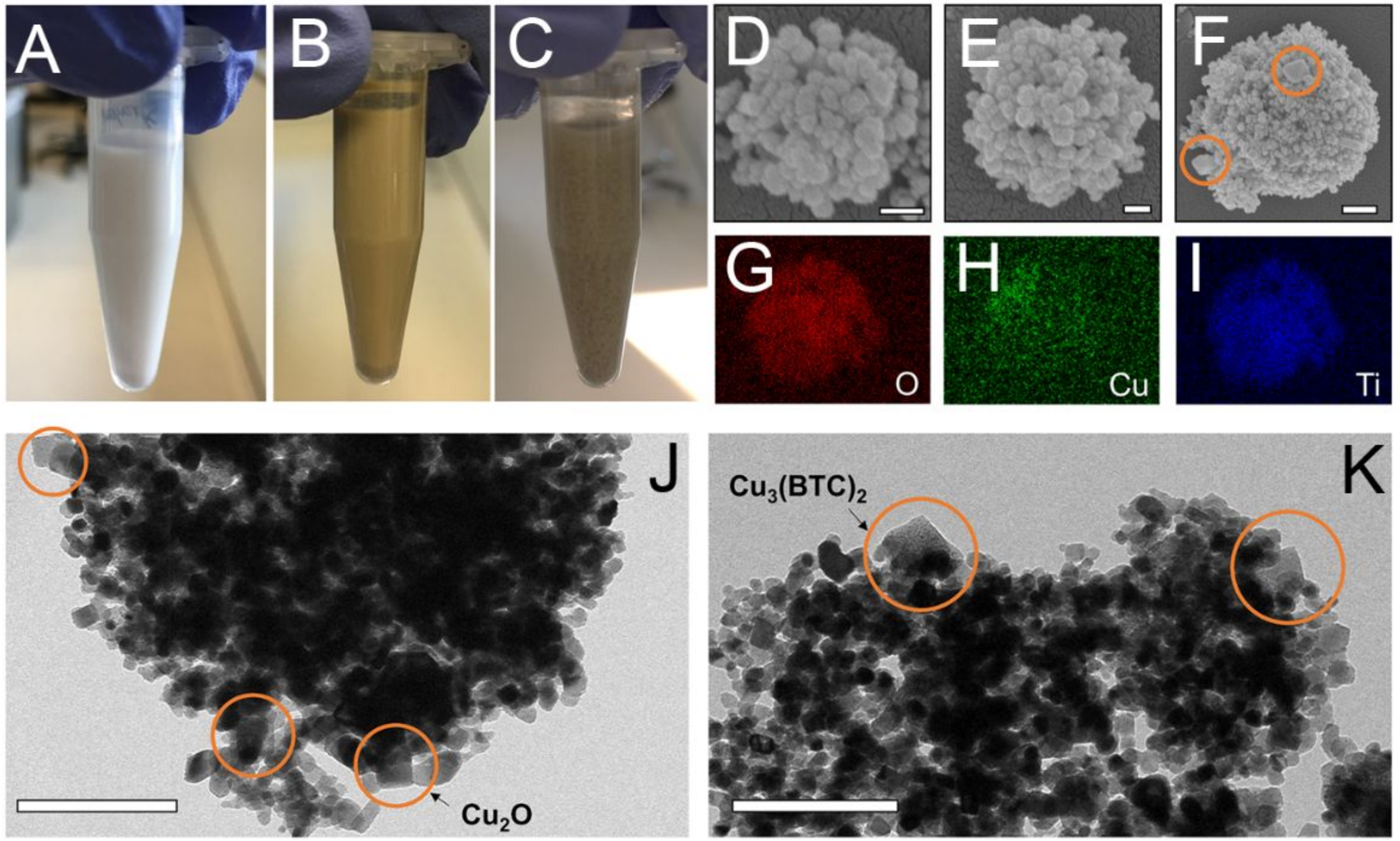


The above figure shows an example of HKUST-1/TiO_2 hybrid catalyst particle design through a microdroplet-based aerosol approach for photocatalytic carbon dioxide (CO_2) capture and conversion, which aims to address the long-standing issues of global warming and energy shortage. More details can be in the article below.

X. He, Z. Gan, S. Fisenko, D. Wang, H. M. El-Kaderi, and **W.-N. Wang***, Rapid Formation of Metal-Organic Frameworks (MOFs) Based Nanocomposites in Microdroplets and Their Applications for CO2 Photoreduction, ***ACS Applied Materials & Interfaces***, **9**(11): 9688-9698 (2017)

Example 2_MOFs-Semiconductor Heterojunctions

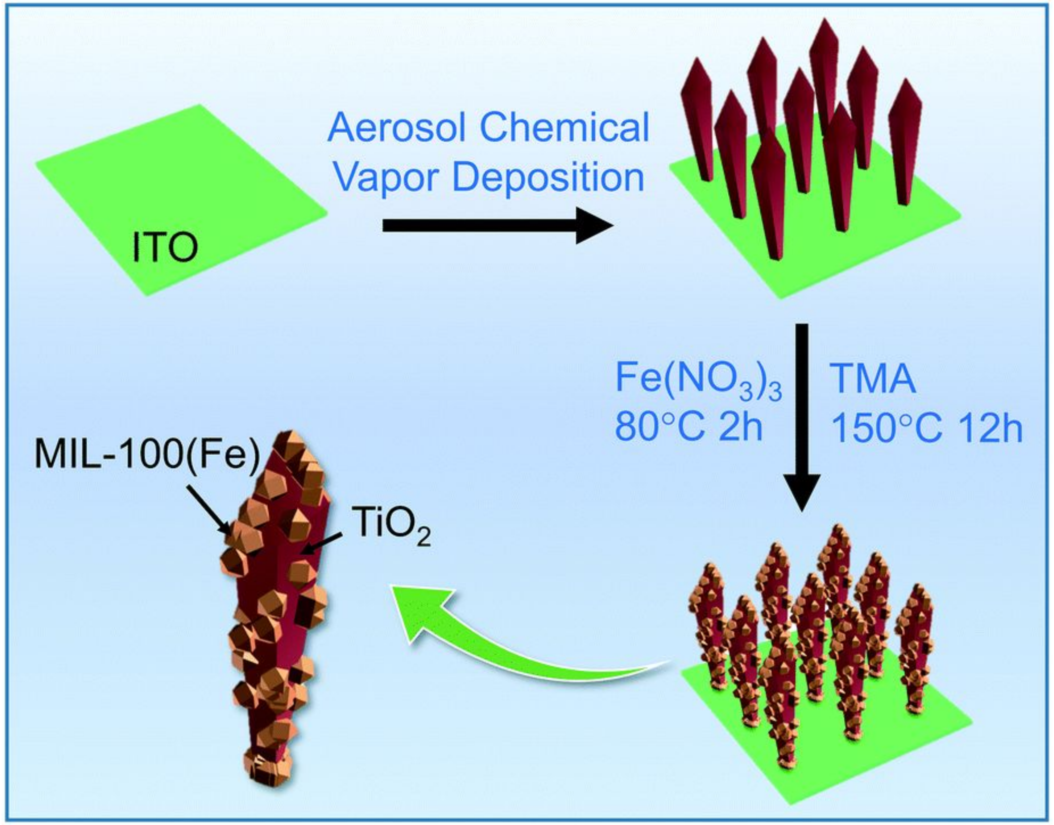


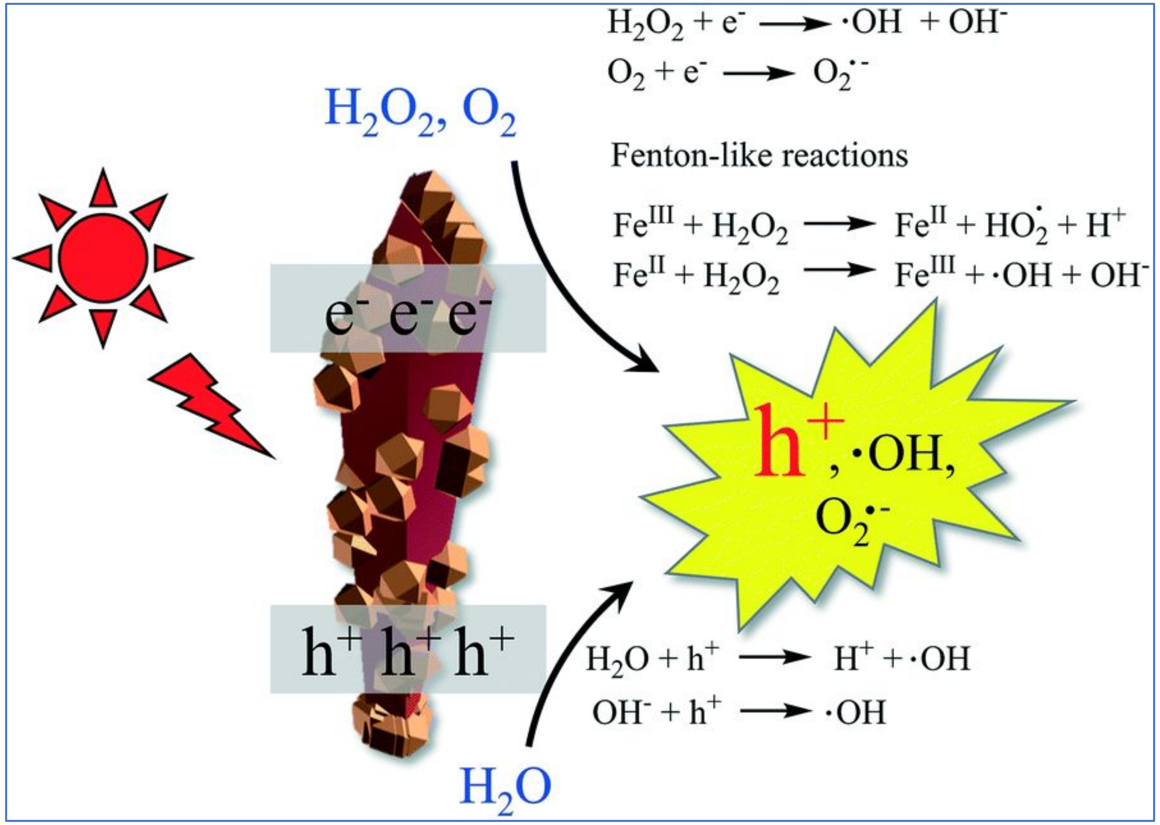


This is another example of MOF-based catalyst design through a microdroplet approach. The left image shows the sequential formation processes of the ternary catalyst for CO_2 photoreduction as well as the corresponding charge transfer and intermediates formation pathways. The right image demonstrates the corresponding characterization results of the particles. Digital images of aqueous suspensions containing (A) TiO2, (B) TiO_2/Cu_2O, and (C) $TiO_2/Cu_2O/Cu_3(BTC)_2$. (D-I) are corresponding SEM and EDX results of the particles. HRTEM analysis of the particles is shown in J and K. More details can be in the article below.

X. He and **W.-N. Wang***, MOF-based Ternary Nanocomposites for Better CO2 Photoreduction: Roles of Heterojunctions and Coordinatively Unsaturated Metal Sites, ***Journal of Materials Chemistry A***, **6**(3): 932-940 (2018)

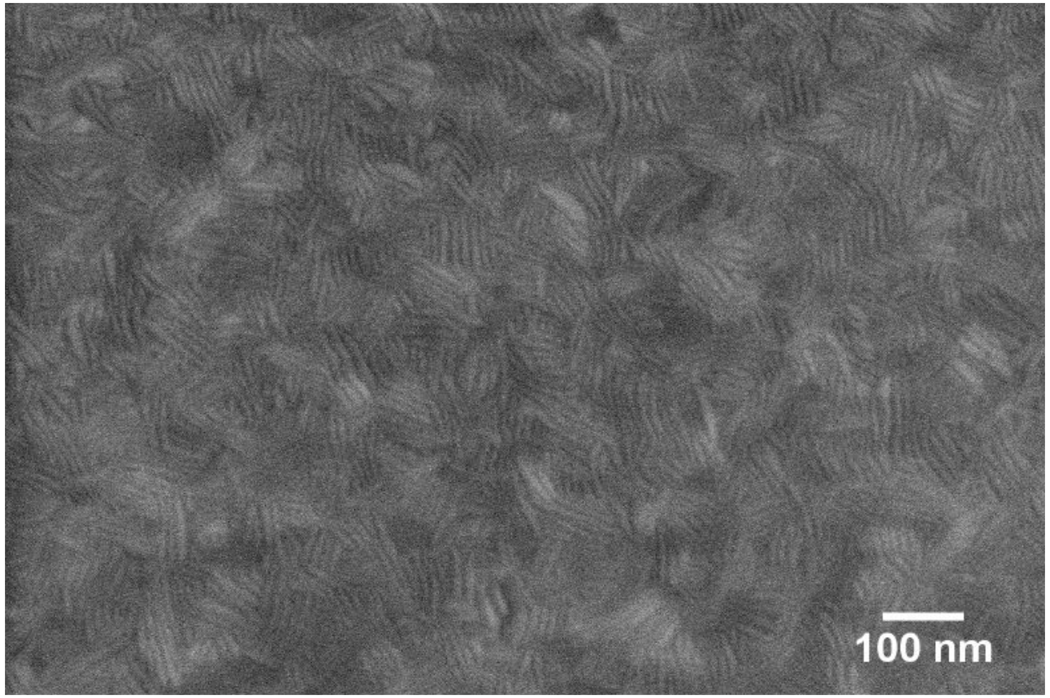
Example 3 _ 1D Nanocolumns for photocatalysis



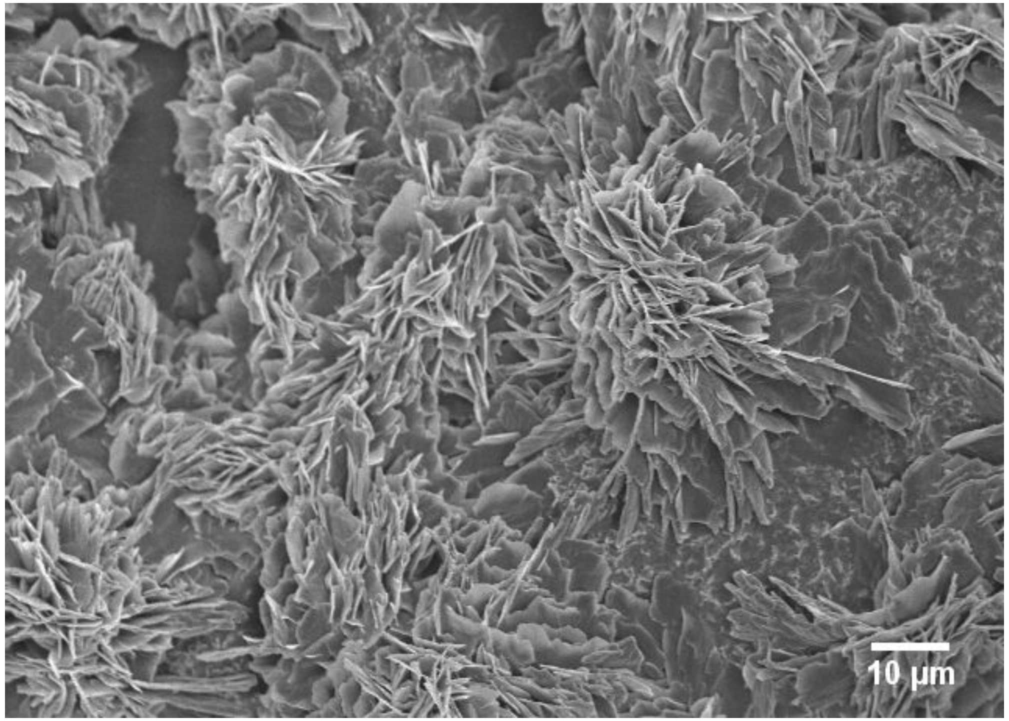


In addition to particles, 1D structured nanocolumns can also be designed and fabricated for photocatalysis. The left figure shows the typical formation steps of MIL-100(Fe)/TiO_2 hybrid nanocolumns and the right diagram demonstrates the possible reaction pathways for photocatalytic degradation of antibiotics. More details can be found in the article below.

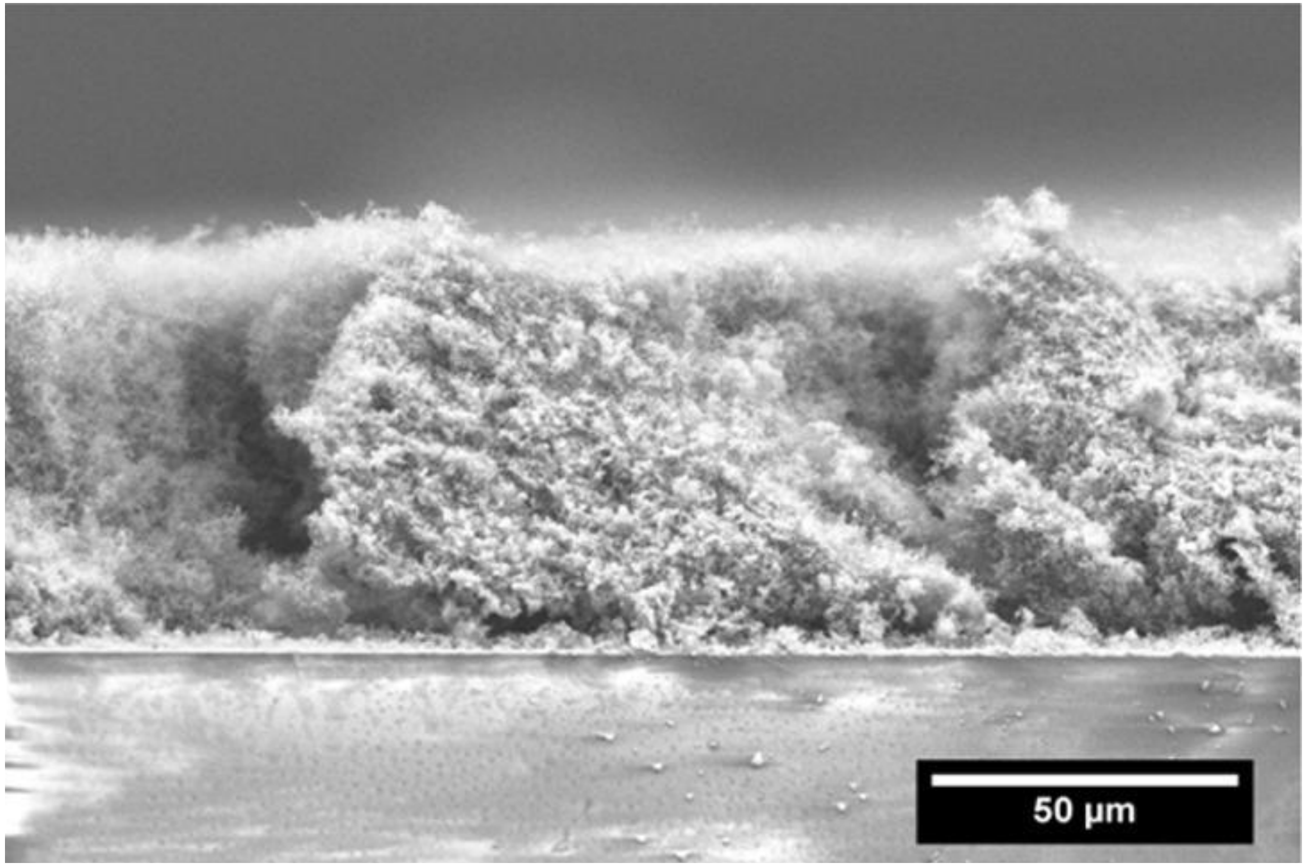
X. He, V. Nguyen, Z. Jiang, D. Wang, Z. Zhu, and **W.-N. Wang***, Highly-oriented one-dimensional MOF-semiconductor nanoarrays for efficient photodegradation of antibiotics, ***Catalysis Science & Technology***, 8: 2117-2123 (2018)



SEM image of sputtered pure tungsten thin film. The needlelike patterns on the surface represent the growth of the body-centered cubic films in the close packed [1 1 1] direction (J. Vac. Sci. Technol. A, 39, 033405, 2021).



SEM image of a cured alkyl ketene dimer coating. This polymer coating shows excellent non-wettability due to its low surface energy and developed micro-patterns (JCIS, 573, 317-327, 2020).



Cross-sectional SEM image of modified carbon soot coating with excellent superhydrophobicity. The soot's inherent stabilization is achieved using a specially-designed cone-shaped aluminum chimney (Applied Surface Science, 369, 341-347, 2016).